THE BURR-BROWN PCI-20000
PERSONAL COMPUTER
INTELLIGENT INSTRUMENTATION SYSTEM

PCI-20000 SYSTEM

USER'S MANUAL

855M131 1.3

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PCI-20000 SYSTEM USER MANUAL
REVISION HISTORY

Version		Revision
1.0		Original
1.1	890125	ECO 89012301: Minor editorial changes, conversion to Ventura format, add letter.
1.2	890324	ECO 89032301: Correction to paging.
1.3	890607	ECO 89050304: Correction to letter.

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Chapter 1: Introduction

Congratulations on your purchase of a PCI-20000 System. You will soon find that it will give you the most flexible and configurable single-board data-acquisition and control system available for the IBM PC(tm) computer and IBM compatibles.

The PCI-20000 System allows you to specify exactly the configuration you need for your job, and buy only that. While most other manufacturers decide for you what mix of digital and analog inputs and outputs your instrumentation application requires, we let you decide for yourself. If your needs change, your system can change with them, without jeopardizing your initial investment.

The PCI-20000 Philosophy

The key concept of the PCI-20000 System is modularity. The system hardware consists of two main types of components: the Carrier and the Instrument Modules.

The Carrier handles all the interfacing to the personal-computer (PC) bus, and provides power, inter-Module communications, and a physical mounting mechanism for the Instrument Modules. Some Carriers can also optionally provide on-board, fully buffered, TTL-compatible digital I/O. Other Carriers optionally support Direct Memory Access (DMA) transfers of data to and from the computer, at very high rates. The block diagram of a typical Carrier is shown in Fig. 1.1.

The Instrument Modules perform the actual data-acquisition tasks, with each Module performing specific functions. All the Modules communicate with the PC and with each other through a proprietary bus on the Carrier—the I^3 Bus(tm)—that is optimized for data acquisition. This Bus not only supports the standard types of memory and I/O accesses found in a computer bus, but also includes provisions for chaining analog, synchronizing, and trigger signals among the Modules.

Some ot the available Modules in the PCI-20000 family include:

- a 12-bit, 16-channel data acquisition system
- a 12-bit, 8-channel high-speed data acquisition system
- a 32-channel analog input expander
- a 32-channel analog expander/sequencer
- a 4-channel programmable-gain simultaneous sample/hold
- a 12-bit, 2-channel digital-to-analog converter
- a 16-bit, 2-channel digital-to-analog converter
- a 12-bit, 8-channel digital-to-analog converter
- a 32-channel buffered digital I/O
- a 5-channel couter/timer/rate generator
- a 2-channel trigger/alarm

and the list is continually growing.

The entire nature of the system can be changed simply by changing the number, type, or arrangement of the Instrument Modules included in the system. Each Module has an identification code which can be read by the computer, so the computer can "learn" any particular configuration of the system.

Since each Carrier can hold up to two or three Instrument Modules, and Modules can be mixed and matched with very few restrictions, the number of different possible systems is very large.

A few of the possibilities include:

- a 128-channel digital I/O system
- a 64-channel single-ended analog-input system with 32 bits of digital I/O
- a complete data acquisition and control system with 8 low-level differential analog inputs, 2 analog outputs, 4 channels of counter/timers, one rate generator, and 16 channels of digital I/O.

Configuring any of the above system examples does not preclude any different configuration later, and that is one of the strengths of the PCI-20000 System. Since any Module may be plugged in or removed at any time, one Carrier and an assortment of Modules could be used to configure a different system for every application.

Although variability, flexibility, and versatility are key features, an additional benefit of the PCI-20000 System—usually mutually exclusive with all these features—is optimization for a single task. If you have a dedicated application which requires a known, limited and unchanging configuration, you can efficiently achieve that without buying a lot of capability you don't need. For example, a system to control an oven could be implemented with one A/D Module, and the optional digital I/O on a Carrier. Since the application does not require counter/timers or analog outputs, you need not buy those Modules. With most other data-acquisition boards available, you would be paying for functions whether or not they were to be used.

How to Use the PCI-20000 Manuals

In order to gain the maximum benefits from your PCI-20000 System, the user should be aware that the modularity of the hardware is reflected in the modularity of the User's Manuals for the components of the System. This means that each Carrier, Instrument Module, Termination option and Software Support package has its own individual User's Manual. Tying together all the pieces of the system is the function of this System User's Manual, and it should be read in conjunction with the individual User's Manuals for the components you have purchased.

If the user is relatively new to computers and computer-based instrumentation, there will be several new concepts to learn. In order to get the most from the PCI-20000 System, computer terminology as well as signal-interfacing concepts

must be well understood. A review of these topics is contained in Appendix A, Introductory Concepts.

Another comprehensive source of information for the user is the Burr-Brown *Handbook of Personal Computer Instrumentation.* This handbook includes tutorial and applications information on data acquisition, as well as configuration guides for personal-computer based instrumentation systems, and data sheets on the individual systems and software.

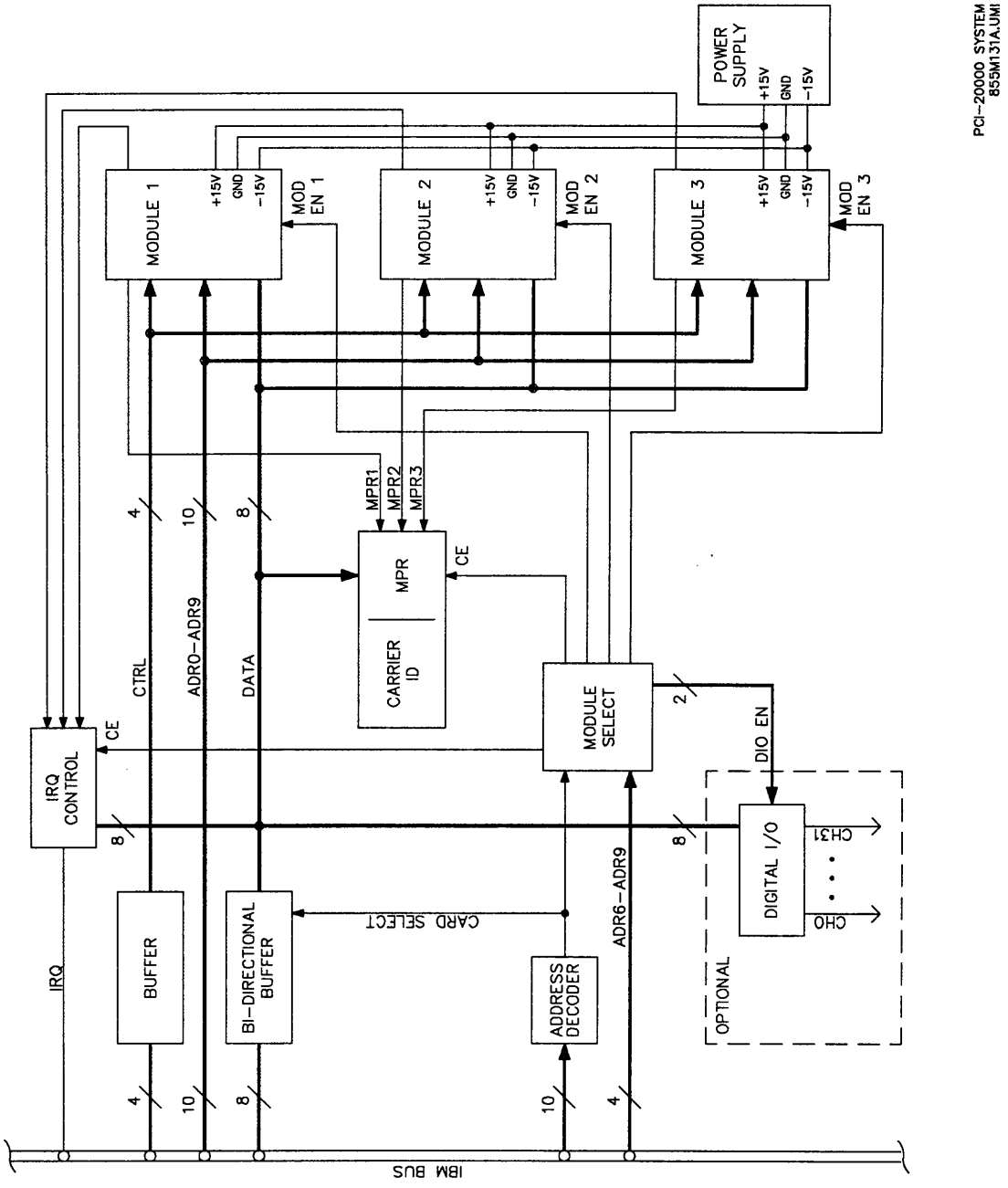


Figure 1.1 PCI-20001C Carrier Block Diagram

Chapter 2: Getting Started

2.1 Introduction

This chapter tells you how to configure and install your system. Configuration information is given at a high level only. For in- depth configuration information, please read the manual that goes with the particular component you want to configure. The majority of this chapter is composed of step-by-step installation instructions.

First, make sure you have everything you will need in order to get your system installed and running. You need:

1. At least one Carrier.
2. One or more Cables to connect your Carrier to the outside world.
3. At least one strain-relief bracket, if necessary. If you have more than two or three cables, or if your cables are shielded (analog I/O cables), you may want to use a second strain-relief bracket to relieve crowding.
4. Termination Panels to connect your Cables and equipment to.

You may also have:

1. One or more Modules to plug into your Carrier. If you have more than one Module, you will also need a second strain- relief bracket (purchased separately).
2. One or more PCI-20061A-1 or PCI-20061A-2 Inter-Carrier Cables, purchased separately (for use with two or more PCI- 20041C Carriers in a multiple-Carrier configuration).

2.2 System Preparation

Before you begin installing your PCI-20000 System, read through this chapter. Also read through the User's Manuals for the Carriers and each of the Modules in your system. Decide which switch settings and jumpers are appropriate for your application, then configure your sytem accordingly. We recommend that you make a list of these configuration settings for each Carrier and its Modules. Keep this list with your manuals for reference. Convenient forms for this purpose may be found at the end of this chapter.

Make sure the factory address-switch setting on the Carrier will not conflict with anything else in your computer, including any other option boards. If you are installing more than one Carrier in your computer, you *must* change the address of

all but one Carrier, so that the Carriers do not interfere with each other. Refer to the section "Carrier Addressing", in the appropriate Carrier manual, for details.

Install any required jumpers on the Carrier(s). Refer to the section on Jumper Settings, in the appropriate Carrier manual, and in the User's Manuals for your Modules, for details. Update your notes with the addressing and jumper information. Please move plug-in jumpers only; soldered-in jumpers must remain where they are.

2.3 Preparing Modules

Any Module can be used in any Module position on the Carrier. However, two or more Modules that are used together may need to be located in a particular physical relationship to one another, depending on how the modules use the analog daisy chain and SYNC signals. Figure 2.3 illustrates Module positions and installation.

2.3.1 Analog Daisy Chain

Some Modules may pass analog signals to a second Module through the I^3 Bus analog daisy chain. In order for this to work, on the PCI-20001C and PCI-20041C, the Module must be in the next lower- numbered position from the Module that is to receive its analog signals. For example, if you are using an Analog Expansion Module with an Analog Input Module, the Analog Input Module could be placed in position 3, and the Expansion Module would then be placed in position 2. A second Expansion Module could be placed in position 1. If an Analog Expansion Module is used on the PCI- 20098C, the Module should be placed in position 1. A second Expansion Module should be placed in position 2.

Refer to the individual Module User's Manuals for the specific requirements of your Modules. On some Modules, jumpers must be placed in order to make use of the analog daisy chain. The Carrier Manuals contain detailed descriptions of the I^3 bus analog daisy chain.

2.3.2 SYNC Signals

The SYNC OUT signal of some Modules may be used to drive SYNC IN of a second Module through the I^3 bus, using the SYNC IN/SYNC OUT system. The routing of SYNC signals is determined by jumpers on the PCI-20001C and PCI-20041C, which must be placed before the Modules are installed. These jumper placements are described in the appropriate Carrier manuals. The routing of SYNC signals on the PCI-20098C is done with software.

Refer to the individual User's Manuals for descriptions of how your system uses SYNC signals. Your particular application may or may not require use of the SYNC

bus. Jumpers must be placed on some Modules, as well as on some Carrier, in order to make use of the SYNC bus.

You may have to set jumpers on the Modules to select such options as converter range and amplifier gain. You may also have to set jumpers to determine the source of various enable and control signals to the Modules. If your Modules have calibration adjustments, you may wish to perform those adjustments prior to installing your complete system.

Consult the individual Module User's Manuals for any special configuration requirements of your Modules. Then, plan how you will arrange the Modules on your Carrier(s), and add this information to your notes.

2.4 Installing the PCI-20000 System

The procedure for installing your PCI-20000 System in an IBM PC is described below. The procedure for installing the assembly in other machines will differ somewhat, but will be similar in nature.

OPENING YOUR COMPUTER

1. Turn off the power to your computer, and unplug it.

> WARNING
> **Lethal voltages exist inside computers. Always ensure that power is removed before opening the case. Only qualified technicians should install, modify, or adjust equipment inside any computer unit.**

> CAUTION
> **Failing to turn off the power when inserting or removing boards will damage the boards and possibly the computer as well.**

2. Remove the five screws on the rear panel of the computer's chassis that hold the cover to the chassis.

3. Carefully slide the cover toward the front of the chassis, lift it up slightly, and remove it.

SELECTING A PLACE TO PUT YOUR CARRIER

4. Select two adjacent expansion slots for each Carrier/Module assembly. You will be plugging the Carrier into the leftmost of these two expansion slots, so that the Modules face the empty slot. We recommend that you choose the two leftmost slots (as you face the back of your computer) for your Carrier. If a PCI-20098C is used without Modules, only one expansion slot is required. In addition to these slots, we recommend that you have an additional two slots (next to them) temporarily empty in order to give you plenty of working room. Finally, when you reinstall any boards you have temporarily removed, you may want to place them closer to your power supply in your computer.

INSTALLING THE FIRST STRAIN-RELIEF BRACKET

5. If you are using two strain-relief brackets, remove the covers from both expansion slots in the rear of the computer. If you are using only one strain-relief bracket (the one for the Carrier), remove the cover from the leftmost expansion slot, where the Carrier will be installed. Disassemble the strain-relief bracket(s) by following the instructions in your bracket installation guide. Secure the mounting bracket portion in the expansion slot with the screws that held the slot cover. Do not tighten this screw at this time! See Fig. 2.1. The PCI-20098C does not require a strain-relief bracket. It's bracket is attached to the Carrier and is automatically installed upon insertion of the Carrier.

INSTALLING THE CARD GUIDE

6. Install the supplied card guide at the front of the computer, in line with the slot where the Carrier will be mounted.

INSTALLING THE DIGITAL I/O CABLES ON THE PCI-20001C-2 CARRIER

NOTE: If you have a PCI-20001C-1 Carrier, a PCI-20041C Carrier or a PCI-20098C Carrier, skip this step and go to step 8. If you have a PCI-20001C-2 Carrier, perform this step, then continue with step 8.

7. Install the digital I/O cables. Plug the bottom cable into the right- hand connector (P1). This cable contains I/O channels 0 through 15. Plug the top cable into the left-hand connector (P2). This cable contains I/O channels 16 through 31. Mark the free ends of the cables so you can identify them later when you connect them to the termination panels. See figure 2.2 for an illustration of the locations of P1 and P2.

INSTALLING THE MODULES

8. Install any Modules onto your Carrier. Obtain the Module you are going to install in position 1 (see figure 2.3 for Module position numbers and installation). Locate the nylon standoff shipped with the Module, and plug it into the hole near the edge of the Module opposite the Module's P1 connector.

9. Plug the Module into the Carrier. Be careful not to bend the pins, and make sure not to misalign the Module so that some of the pins miss the connector. The nylon standoff on the Module should line up with the mating hole on the Carrier (figure 2.4). If your Carrier is a PCI- 20001C-2 with digital I/O, its cables should now be sandwiched between the Module and the Carrier.

If you need to unplug a Module for any reason, either to correct a misalignment or to reconfigure your system, use extreme care to avoid bending the connector pins. We have found the best technique is to use your thumbs to press against the Carrier while using your index fingers to press against the upper corners of the Module, with one hand at each corner of the Module. Be very gentle, and take your time to "work" the connectors apart, keeping the Module approximately parallel with the Carrier as it unplugs.

10. Snap the nylon standoff into the mating hole in the Carrier.

11. Locate the interface cable(s) for the Module. (The computer ends of the analog cables are marked "COMPUTER.")

12. Plug the cable(s) into the mating connector(s) on the Module. Refer to Fig. 2.5 for the proper orientation of the cable connectors.

13. Repeat steps 8 through 12 for the Module that is going into position 2. Make sure that its cables lie over the top surface of the previously installed Module and its cables.

14. Repeat steps 8 through 12 to install the third Module in position 3, if available.

15. Label the free ends of the cables for later connection to the appropriate termination panels.

INSTALLING THE PCI-20001C-2 CARRIER

NOTE: **If you have a PCI-20001C-1 Carrier, a PCI-20041C Carrier or a PCI-20098C Carrier, skip this step and proceed to step 17. If you have a PCI- 20001C-2 Carrier, perform this step and then skip to step 19.**

16. Set the Carrier assembly in a convenient place near the left side of the computer, and feed the digital signal cable(s), attached to the Carrier, through the bracket, inside to outside, at your chosen slot. (See figure 2.6.) Be sure the cables are not twisted and will be able to lie flat when the Carrier has been installed.

Hold the Carrier over the slot. Feed all but about one foot of the digital cable(s) through the bracket. Lower the Carrier into the slot. Keep some slack in the digital cable(s), and adjust them as appropriate to keep them from jamming. (The slack in the cables should resemble a backward "S" when viewed from above.) Tilt the Carrier up at the front (above the card guide) as you lower it towards the motherboard. After you are sure the Carrier is aligned properly in the slot, straighten it so the front of the Carrier slides down into the card guide. Then push the Carrier

straight down *gently!* to plug it into the slot connector on the computer's motherboard. (Figure 2.7.)

INSTALLING THE PCI-20001C-1 CARRIER, THE PCI-20041C CARRIER, OR THE PCI-20098C CARRIER

NOTE: **If you have a PCI-20001C-2 Carrier, skip to step 19. If you have a PCI- 20001C-1 Carrier, a PCI-20041C Carrier or a PCI-20098C Carrier, perform this step, then continue with step 18.**

17. Hold the Carrier over the chosen slot, then lower it in. Tilt the Carrier up at the front (above the card guide) as you lower it toward the motherboard. After you are sure the Carrier is aligned properly in the slot, straighten it so the front of the Carrier slides down into the card guide. Then push the Carrier straight down *gently!* to plug it into the slot connector on the computer's motherboard. (Figure 2.7.)

INSTALLING THE DIGITAL I/O CABLES ON THE PCI-20041C CARRIER

18. **If you have a PCI-20001C Carrier or a PCI-20098C Carrier, skip to step 19. If you have a PCI-20041C Carrier, perform this step, then continue with step 19.**

Thread the digital signal cables through the strain-relief bracket, from the outside of the computer. Plug the ends marked COMPUTER into connectors P5 and P6. (See figure 2.8.)

Install the card retainer. Loosen the screw holding the bracket, and slip the retainer under it. Align all the parts, and tighten the screw.

If you have purchased several PCI-20041C Carriers for use in a multiple- Carrier configuration, and if you have purchased one or more PCI-20061A Inter-Carrier Cables, plug these cables in.

Locate the small hole in the top edge of the Carrier, at the rear. Fasten the strain-relief bracket to the Carrier through this hole, using the small screw that was furnished with the bracket for this purpose. Be careful to avoid dropping the screw into the computer. (Figure 2.9.)

Pull the slack out of the digital cable(s) at the back of the computer. Guide the cables by hand as you do so, to avoid scraping them on the bracket or slot opening.

INSTALLING THE SECOND STRAIN-RELIEF BRACKET

19. If you have a second strain-relief bracket, install it in the rear panel at the slot next to your Carrier (on the Module side). Start the hold- down screw (removed with the slot cover in a previous step) into the computer's frame, but *do not tighten the screw at this time.*

20. Feed the Module cables through the second strain-relief bracket at the back of the computer. Make sure that the cables are oriented so that they won't have to be

twisted in order to plug them in. Figure 2.10 is an exploded view of what your system might look like at this point.

FINAL ADJUSTMENTS

21. Adjust the strain-relief brackets to a vertical position and tighten the mounting screws.

22. Looking at the rear of the computer, push each set of cables to the right, and place the cable clamping plates over the screws. Install the pairs of thumb screws to secure the plates against the cables. Do not overtighten. (Figure 2.11.)

23. If you are installing additional Carrier/Module assemblies, repeat steps 4 through 22 for each of them.

24. Replace any computer cards that were removed in step 4 above.

25. Replace the computer's cover, using the five screws previously removed. Installation is now complete.

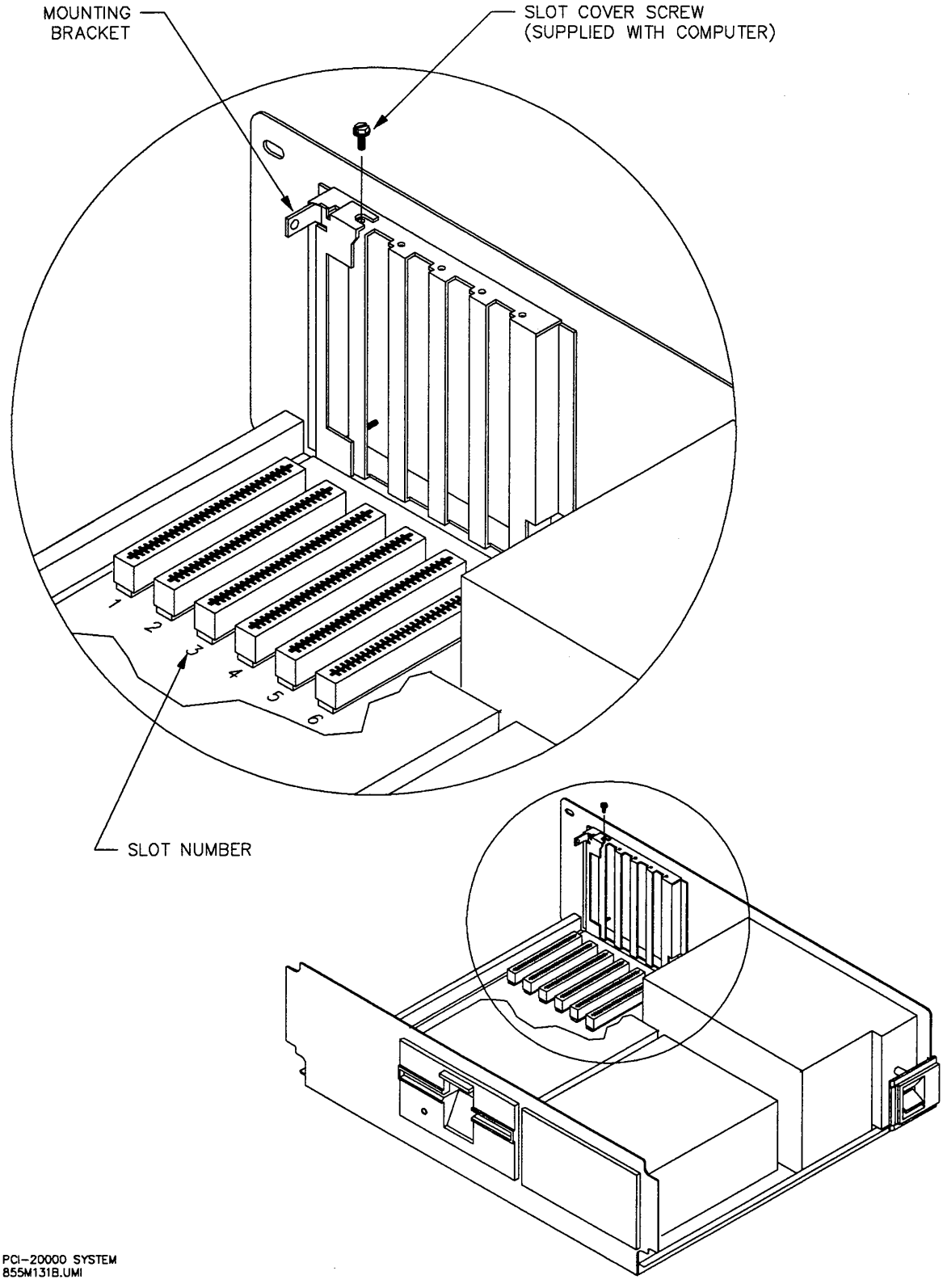


Figure 2.1 Strain-relief bracket installation

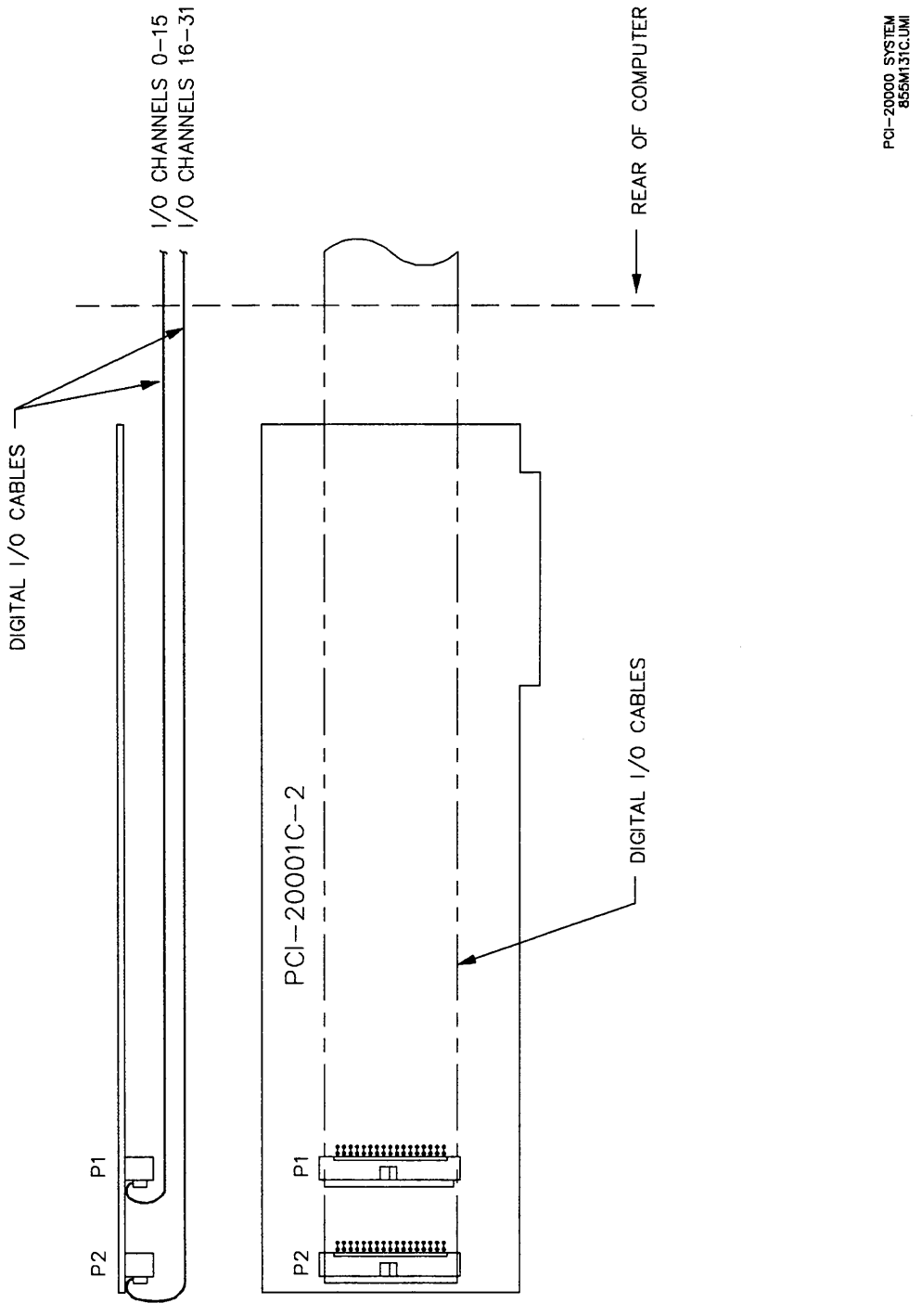


Figure 2.2 PCI-20001C-2, connectors P1 and P2

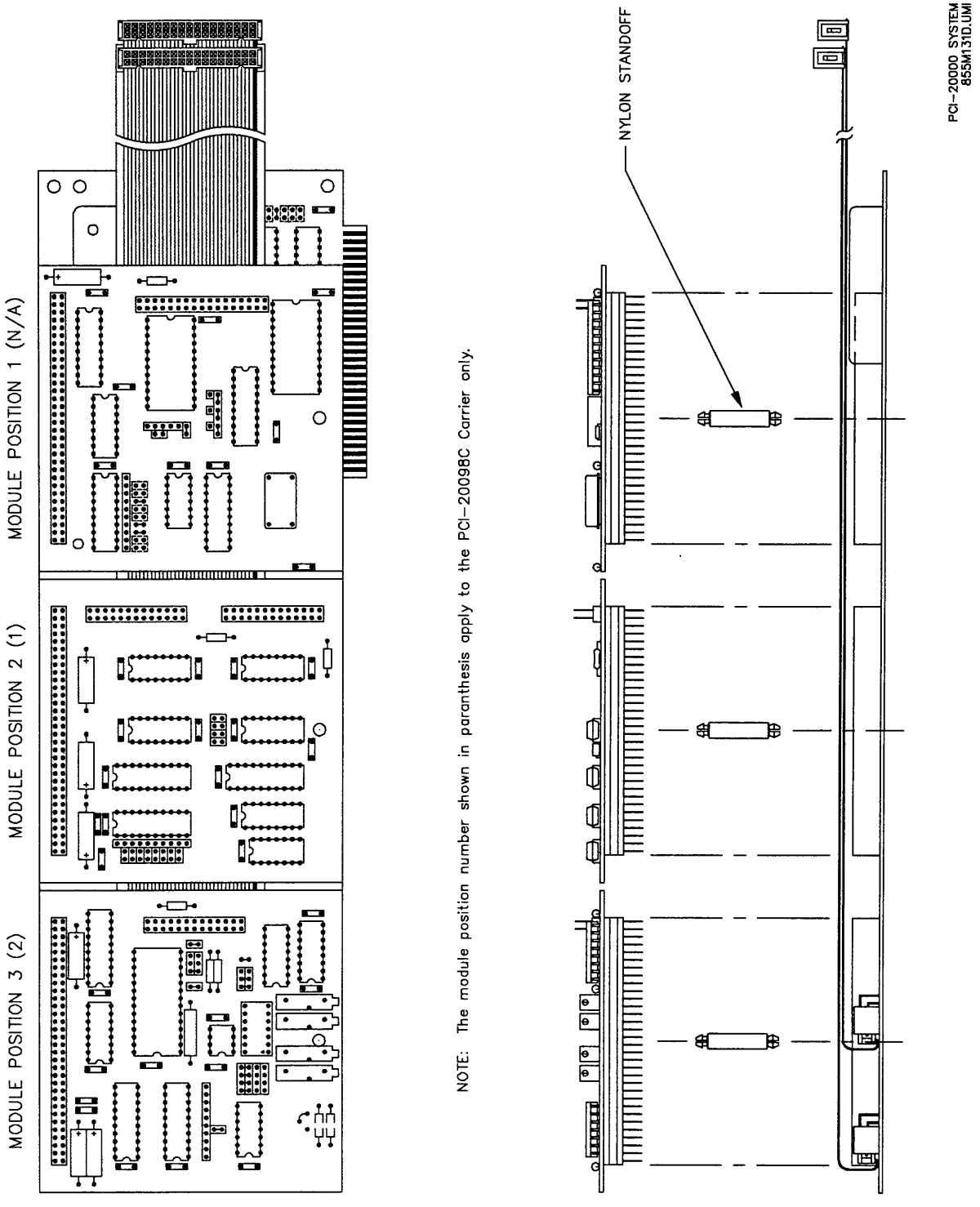
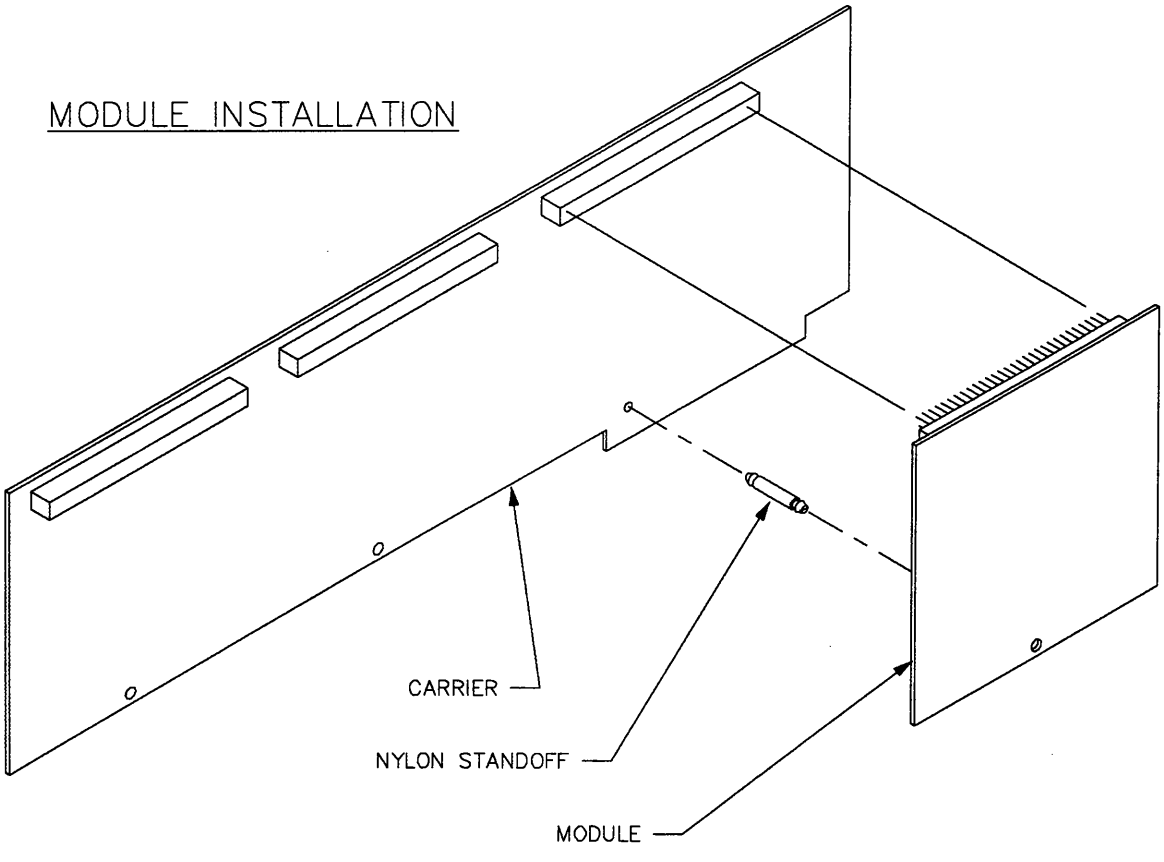

MODULE POSITION 1 (N/A)
MODULE POSITION 2 (1)
MODULE POSITION 3 (2)
NOTE: The module position number shown in paranthesis apply to the PCI-20098C Carrier only.
NYLON STANDOFF
PCI-20000 SYSTEM
855M131D.UMI

Figure 2.3 Module position numbers and installation



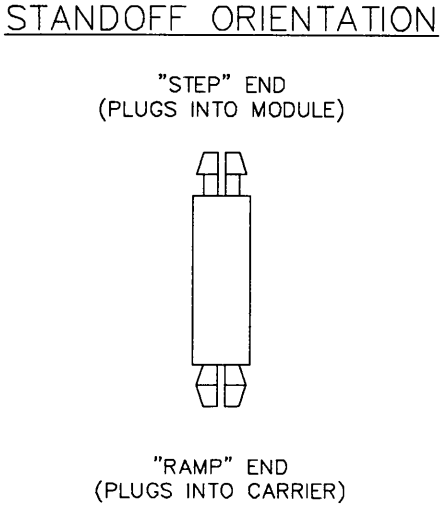


Figure 2.4 Module installation

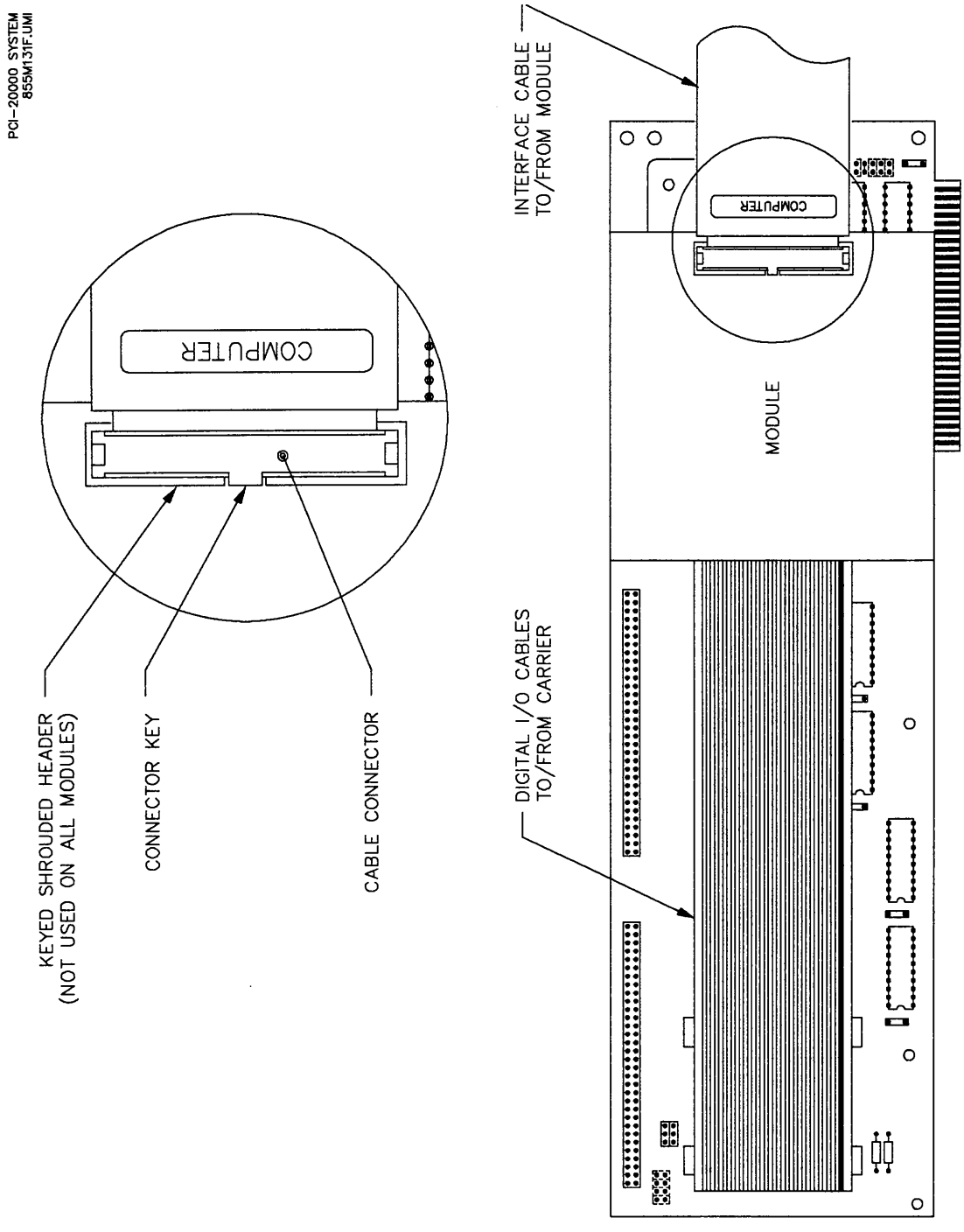
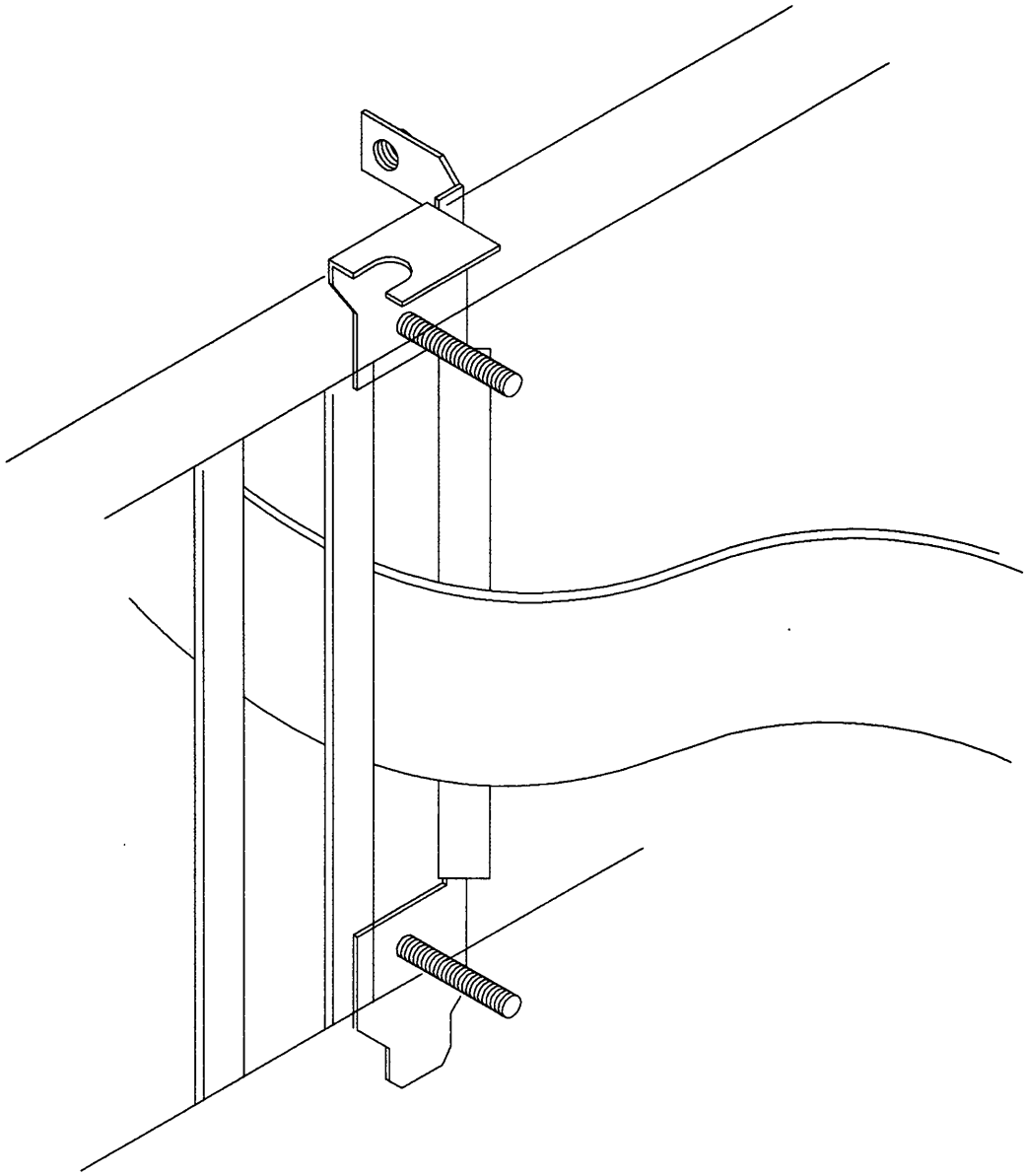


Figure 2.5 Proper orientation of cables



PCI-20000 SYSTEM
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Figure 2.6 Threading cables through the bracket

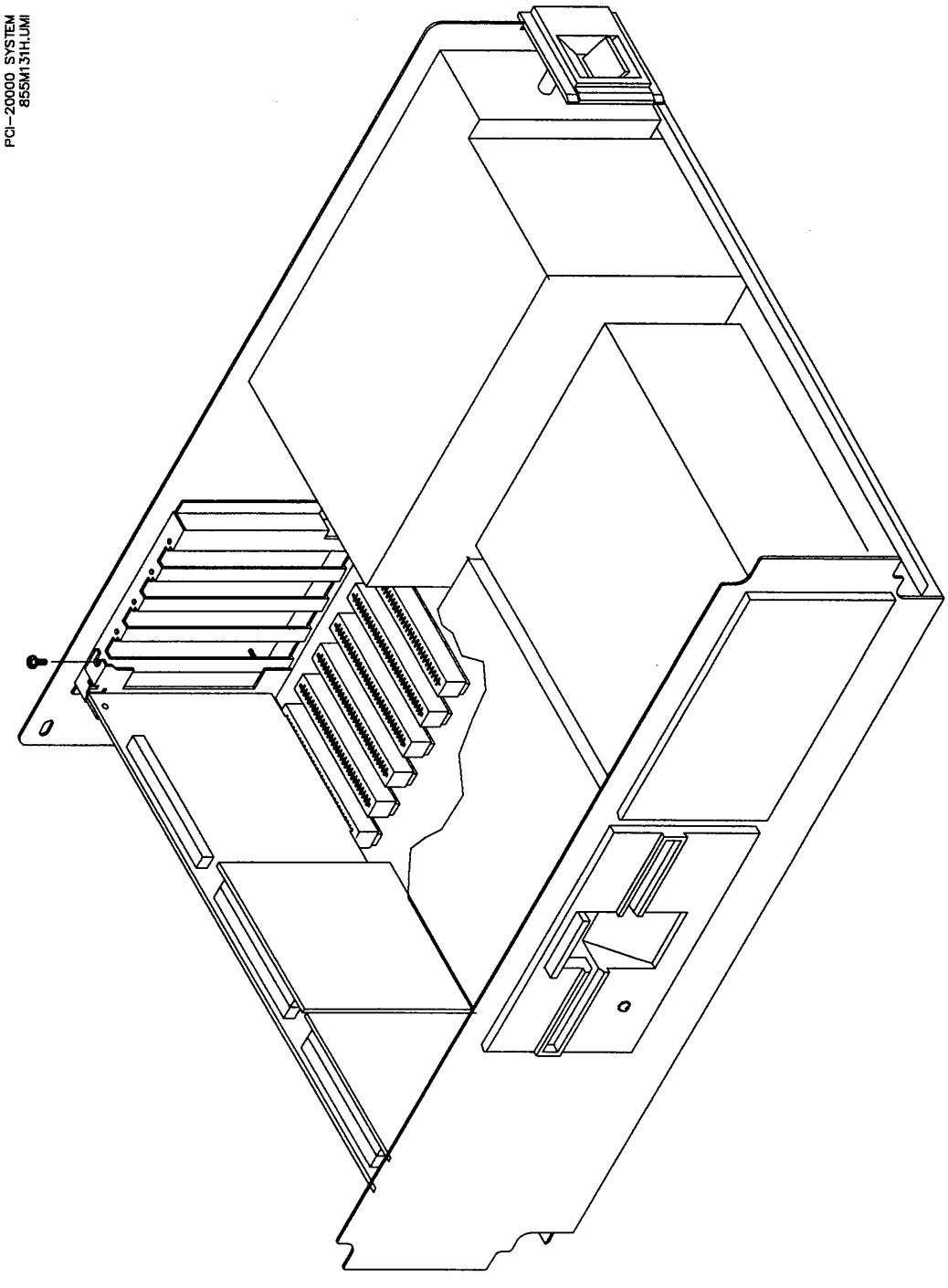

Figure 2.7 Installing the Carrier in the computer

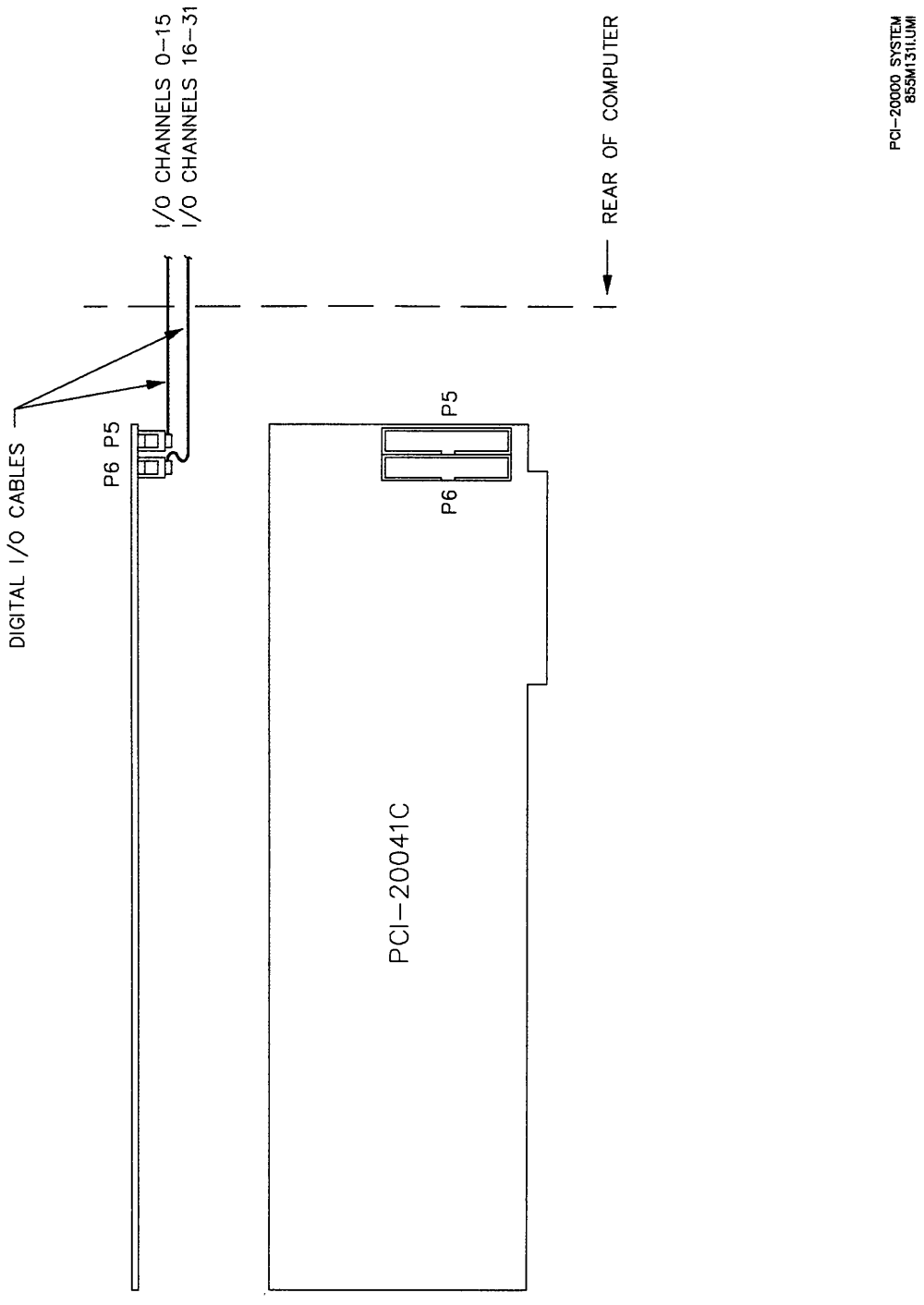

Figure 2.8 PCI-20041C, connectors P5 and P6

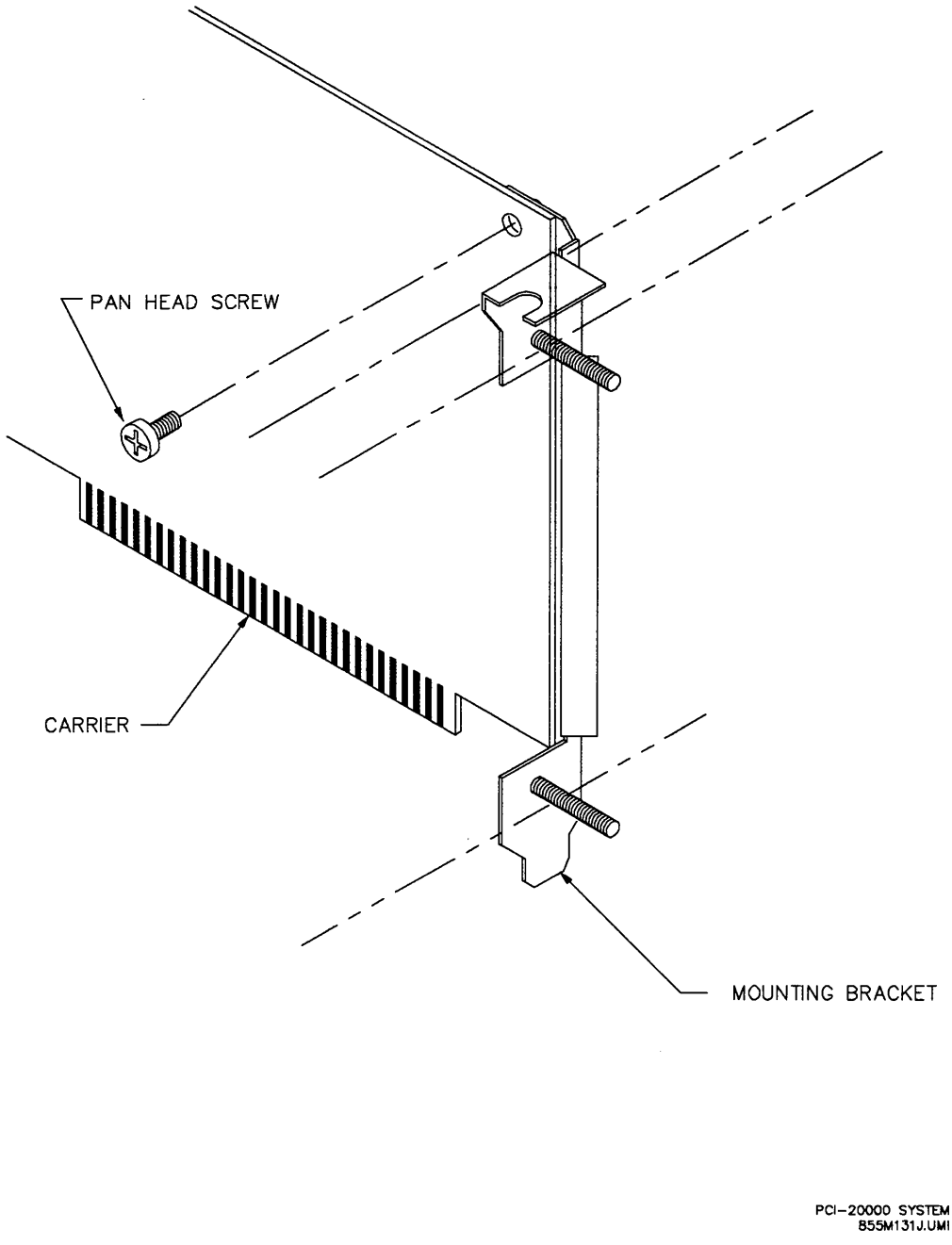

Figure 2.9 Attaching the bracket to the PCI-20041C

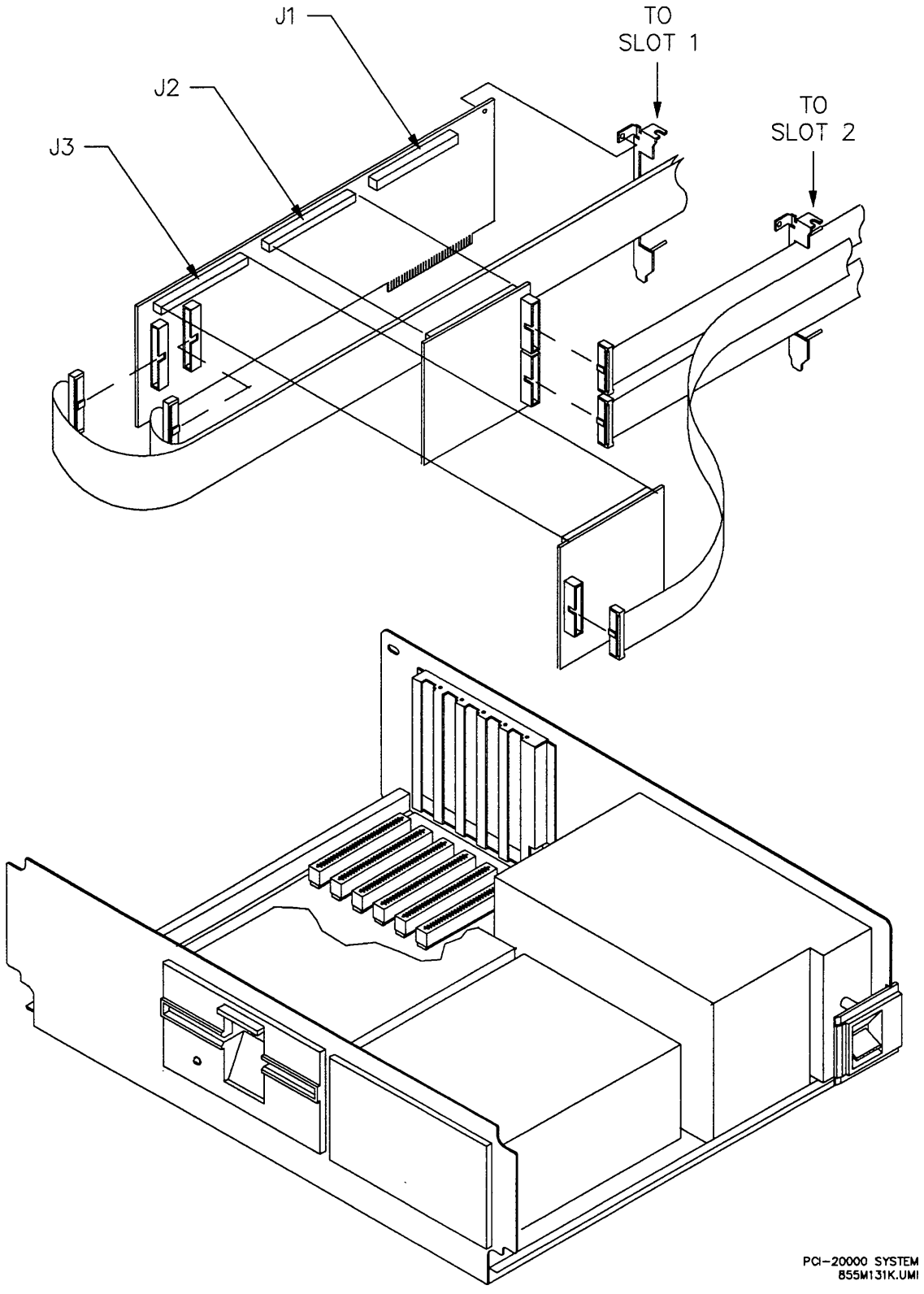

Figure 2.10 An exploded view of an installed system

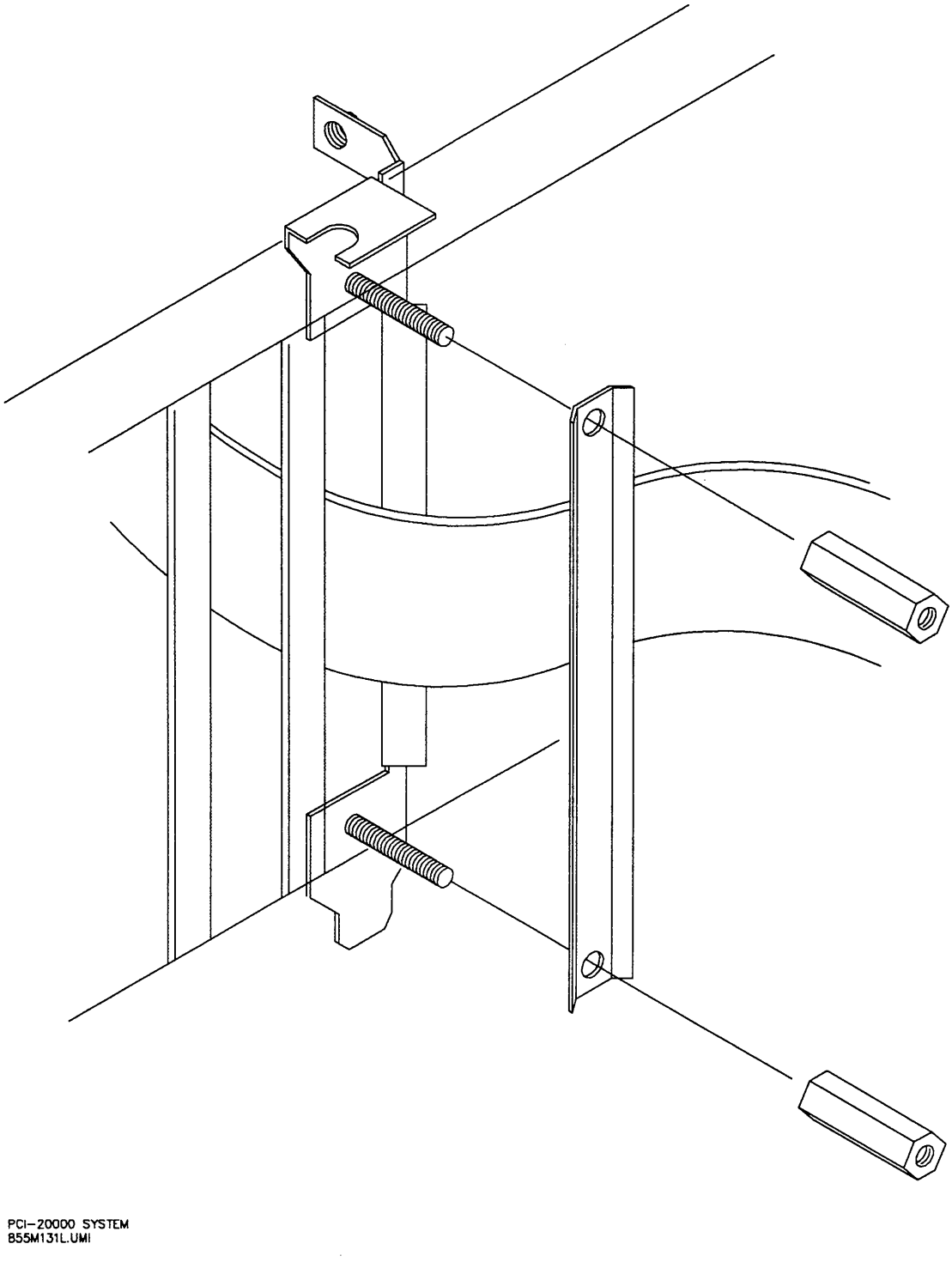

Figure 2.11 Installing the cable clamping plate

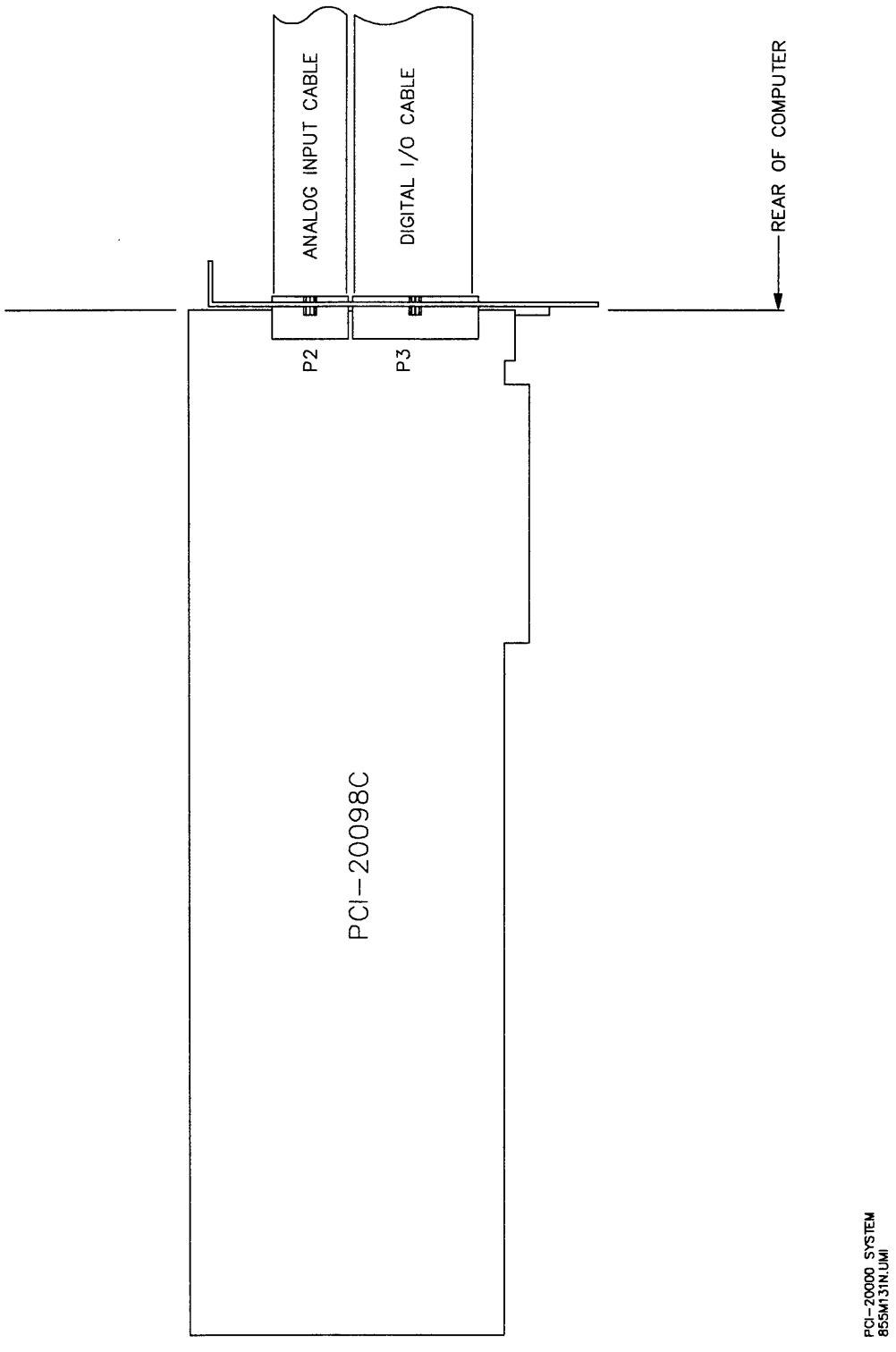

Figure 2.12 PCI-20098C, connectors P2 and P3

Chapter 3: System Configuration

3.1 The I^3 Bus

One of the primary functions of a Carrier is to provide translation from the I^3 Bus, which connects the modules to each other, to the IBM PC(tm) bus. The I^3 Bus is shown in Fig. 3.1. The unused pins in the connector are reserved for future versions of the Bus on other Carriers. A description follows of the I^3 Bus signals.

Notes:

1. The symbols in the "Type" column have the following meanings:
I —Input to Module
O —Output from Module
B —Bidirectional
2. A "*" suffix on a signal name indicates a low-true signal.
3. Some signals are bused across all Instrument Module positions, and some are unique to each position. Some signals that are not bused are identified with an "n", which stands for 1, 2, or 3, depending on the Module Positions in which they appear.

I^3 Bus Signals

Type	Name	Description/Comments
B	BD0 - BD7	Data Bits 0 through 7.
I	nME*	Module Enable. A low on this line enables the Module to be read from or written to. This signal is not bused.
O	nMPR*	Module Present. This line is grounded by the insertion of an Instrument Module. This signal is not bused.
I	BA0 - BA3	Address Lines 0 through 3.
I	A4 - A9	Address Lines 4 through 9.
I	nIOS*	I/O Select.Tied to the ME* line in this implementation. This signal is not bused.
I	BRD*	Read. This line, in conjunction with a valid ME*, indicates data is to be read from the Module to the computer.
I	BWRT*	Write. This line, in conjunction with a valid ME*, indicates that data is to be written from the computer to the Module.
I	BRST	Reset. A high on this line initializes all Modules to a known state.
I	BCLK	Clock. Driven by the 4.77 MHz clock from the computer.
O	nIRQ0*	Interrupt Request 0. Indicates that the Module needs service. Interrupts to the computer are enabled or disabled on the Carrier. This signal is not bused.
I	nSYNCIN	Synchronization Input. Used to synchronize the operation of two or more modules. This signal is not bused.
O	nSYNCOUT	Synchronization Output. Used for synchronizing Instrument operation. This signal is not bused.
I	nI0a, nI0b	Analog input pair 0. Used as a ± 10V analog input to the Module. This pair is not bused. It comes from the O0a,b pair of the previous Module.
I	nI1a, nI1b	Analog input pair 1. Used as a ± 10V analog input to the Module. This pair is not bused. It comes from the O1a,b pair of the previous Module.
O	nO0a, nO0b	Analog output pair 0. ± 10V output from the Module. This pair is not bused. It goes to the I0a,b pair of the next module.
O	nO1a, nO1b	Analog output pair 1. ± 10V output from the Module. This pair is not bused. It goes to the I0a,b pair of the next module.
I	+5V	Five volts, digital power (two lines).
I	DGND	Digital Ground (two lines).
I	+15V	Plus fifteen volts, analog power.
I	-15V	Minus fifteen volts, analog power.
I	AGND	Analog Ground. (Not connected to DGND on Instrument Modules.)

3.2 Signal Interfacing

The external electronic signals that must be dealt with by your computer system fall into two basic categories: digital and analog. A digital signal is one that exists in one of two states, on or off. An analog signal is a value which varies continuously over some range. We will describe five basic types of I/O which can be implemented with the PCI-20000 System. These are: digital input, digital output, analog input, analog output, and special-purpose I/O.

In order to use the PCI-20000 System effectively for instrumentation or control, the user must have an understanding of the signal requirements of the Instrument Modules, as well as the characteristics of the signals in the system being controlled. Some applications may require little more in the way of interfacing than a Termination Panel with convenient screw connections for the I/O signals. Other applications may require elaborate isolation, protection, and filtering circuitry. Low-level signals may also require special shielding to prevent noise contamination. The PCI-20000 System includes a variety of termination options which should satisfy most needs. The following discussions are intended to provide some general background for evaluating the interfacing requirements of your application.

3.2.1 Digital Input

A digital input signal is one which can be in only one of two states. Such signals can be generated by switches, relay contacts, and light sensors, as well as digital logic circuitry.

A digital input signal ordinarily passes through a level-conversion stage, to insure that the "on" and "off" levels are within the range of the TTL levels sensed by the Instrument Module or Carrier circuitry. The simplest type of level conversion is a dropping resistor or voltage divider. High-voltage inputs may require optical isolation; low-voltage inputs may require amplification. Noisy signals require filtering or Schmitt triggers.

The converted signal is grouped with seven other similar signals, which would probably be connected to other digital inputs. These eight signals form an **input register** on the I^3 Bus. When the input register is read, each signal is represented as a 1 or a 0. A switch or other digital input may be connected in such a way as to produce a 1 bit when it is off and a 0 when it is on, or vice versa.

3.2.2 Digital Output

A digital output, like a digital input, is a signal which can be in only one of two possible states: on or off, 1 or 0. Digital output signals are used to control such things as lights, motors, and relays.

Eight digital output signals are grouped together in **output registers** on the I^3 Bus, similar to the digital input registers described above. When data is written into a register, TTL-level signals appear on the output lines corresponding to the 1s and 0s of the data byte. The output interface can be configured so a 1 data bit corresponds to an "off" signal and a 0 data bit corresponds to an "on" signal, or vice versa.

Each output line may be connected to a level-conversion block, which translates the interface signal levels to field signal levels. Since little power is available from the TTL output, the output signal may be used to control an external circuit through a transistor or relay switch. If a relay or other inductive load is used, diodes may be required for protection of the digital output circuitry. Additional protection, such as opto-isolators, may be required for switching high currents or AC circuits.

3.2.3 Analog Input

An analog input provides a means of measuring a continuously variable voltage or current signal. An analog measurement generates a number which is linearly related to the value of the voltage or current, to a specified accuracy and resolution.

Since in a computer all data is represented digitally, analog measurements must be converted to a digital form in order for a computer to manipulate them. This task is accomplished by an analog-to-digital converter (A/D or ADC), which may be part of a Data Acquisition System (DAS). Because such converters are expensive, a number of input signals are multiplexed to use the same converter. The multiplexer switches several input signals, or channels, one at a time into the A/D. The signals may be passed through an amplifier before being input to the A/D. The output of the A/D appears in one or more digital registers (depending on the resulution of the converter), which are accessed through the I^3 Bus. Software controls the selection of channels, triggering of the conversion, and control of a programmable-gain amplifier (if any) through a special control register.

The relationship of the digital value produced by the conversion to the input signal level depends on the resolution, or number of bits, of the converter as well as the input voltage range. For example, consider a 12-bit converter with a +-5 volt input range. There are 4096 (2^{12}) possible values of the digital result. The voltage range of -5 volts to +5 volts covers a span of 10 volts. This means that the value of each bit of the A/D result is

1 bit = 10 volts/4096 = 2.4414mV (approx)

Therefore, the actual voltage corresponding to any converted value, for a converter with a straight binary code, is

voltage = A/D result * 2.4414mV (approx)

For a converter with a complementary binary code, the voltage is

voltage = (4095 - A/D result) * 2.4414mV (approx)

The voltage scale must be corrected by dividing by the gain of all amplification stages, including any off-board amplification, as well as any on-board amplifier.

The primary considerations for interfacing analog signals to an Instrument Module are to avoid introducing noise and nonlinearity. Input signals may need to be shielded, particularly if they are low level or the environment is electrically noisy and there is considerable distance between the source of the signals and the Module. An amplification stage at the point of measurement may improve the noise immunity of a weak signal. Care must be taken to maintain linearity in all amplification stages, or to correct for nonlinearity in the resulting data. The acceptable level of noise in the data-acquisition circuitry is indicated by a calculation like the one shown above. In this example, noise fluctuations approaching 2mV will begin to degrade the accuracy of the data. Noise levels of 40mV degrade the performance of a 12-bit converter to 8-bit accuracy.

Transducers are used to convert such parameters as temperature, pressure, or strain into voltage levels measurable as analog inputs. Since transducers do not produce a precisely linear conversion of these parameters to voltage, linearization is always a part of the conversion of these measurements to "engineering units." Temperature-transducer outputs also require appropriate temperature references to be supplied for accurate measurements, such as cold-junction compensation for use with thermocouples.

3.2.4 Analog Output

Analog outputs provide voltage or current signals which can be used to drive equipment that operates at variable levels. For example, chart recorders, variable-speed fans, motor-speed controllers, and plotters can be controlled in this way. For analog output, a computer requires a Digital-to-Analog Converter (D/A or DAC). A D/A functions in the reverse of an A/D, producing a voltage or current output proportional to binary signals. The same sort of calculation that gave the conversion rule between digital data and analog signal levels for the A/D applies to the D/A as well. Output is accomplished by loading the digital number into an output register. For example, a +-10 volt D/A with offset-binary input accepts valid data in the range 0 to 4095, and the voltage-output range spans 20 volts, so each bit has a value of 4.8828mV (approx), and the output signal voltage is related to the input data word as follows:

output = bit value * data word - offset

where the offset, in this example, is 10 volts.

3.2.5 Special Purpose

The "special purpose" category includes certain types of I/O that do not fall easily into any of the catagories mentioned above. These include event counters, pulsed

outputs, and frequency measurements, which can be regarded for the most part as high-speed digital input or output for interfacing purposes. However, the PCI-20000 supports the use of the Counter/Timer/Rate Generator Module in performing high-speed data acquisition, in addition to the functions mentioned above.

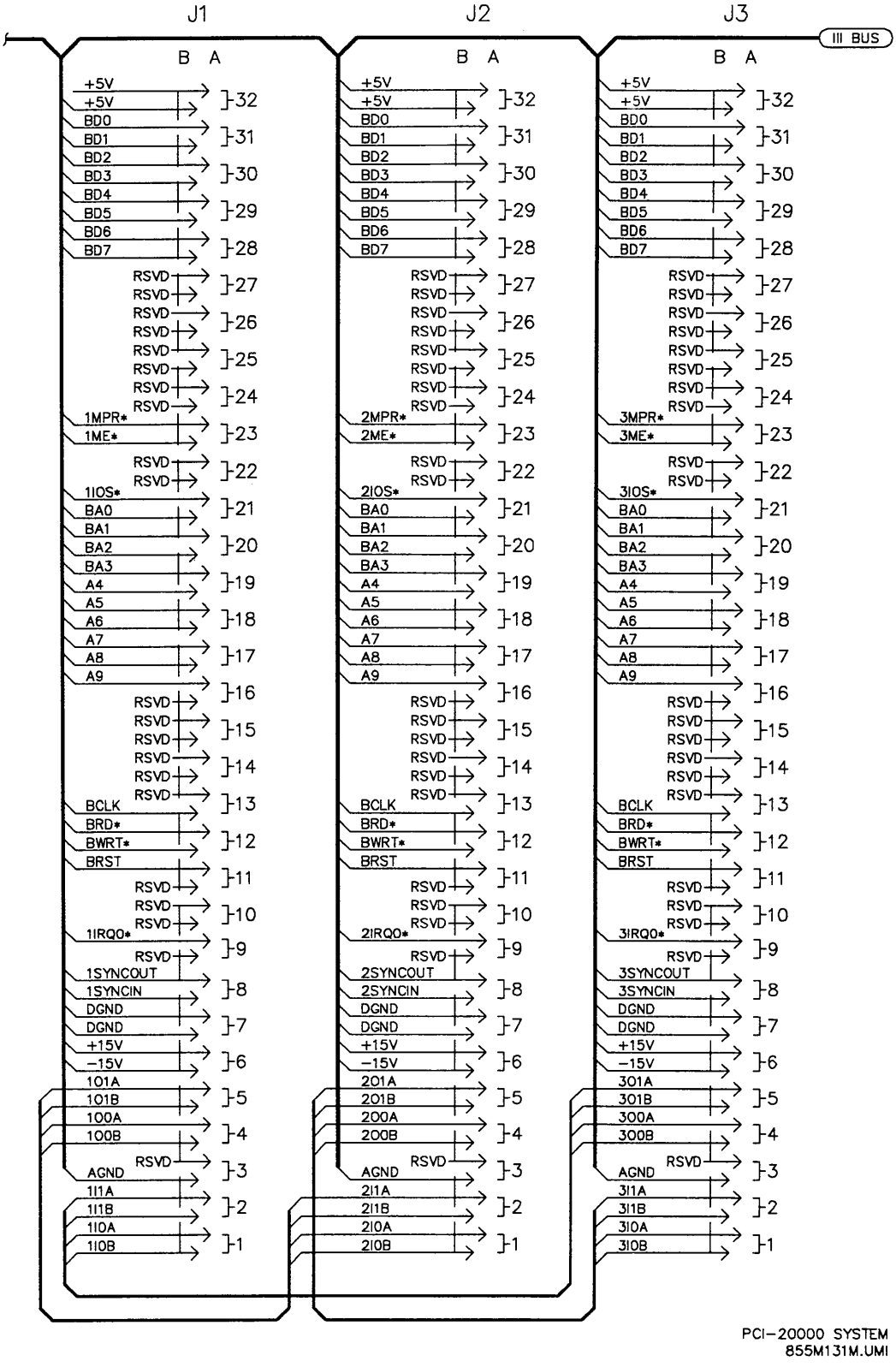

Figure 3.1 PCI-20001C and PCI-20041C I^3 Bus

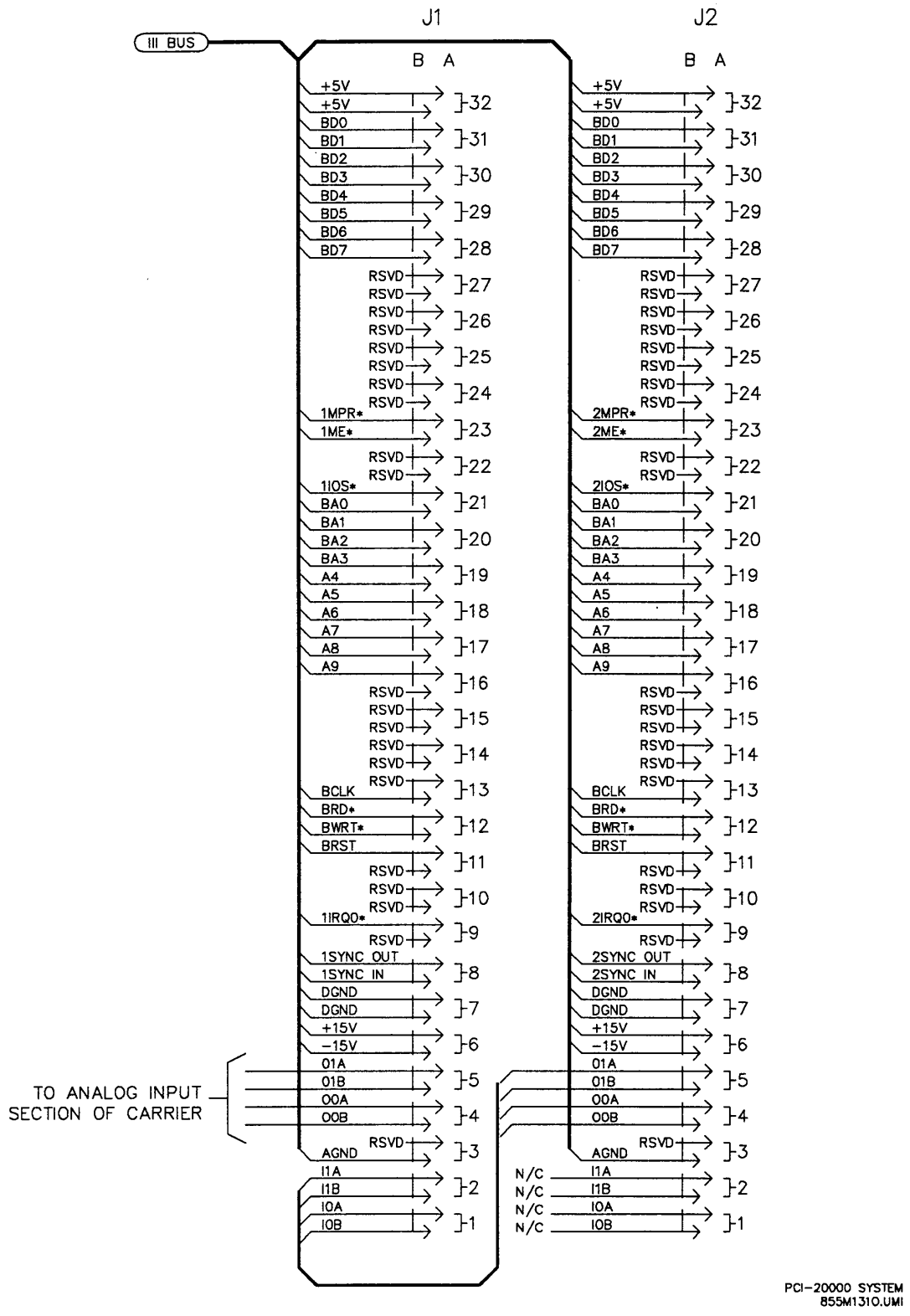

Figure 3.2 PCI-20098C I^3 Bus

Appendix A: Introductory Concepts

In order to get the most from your PCI-20000 System, you will need some understanding of computer terminology: bits, bytes, registers, and addresses; and, signal interfacing: analog and digital signals, signal levels, and so on. This Appendix is provided for PCI-20000 users who are new to computers or computer-based instrumentation, or who may wish a review of some of these topics.

A.1 Computer Architecture

Any computer is composed of three basic sections: a **Central Processing Unit**, or CPU, **memory**, and **peripherals**. The CPU communicates with the memory and peripherals over a set of lines or electrical connections called a **bus**. These lines may be wires, traces on a PC board, or internal connections in an integrated circuit. The different parts of the computer communicate over the bus by setting the voltage levels of the bus lines.

The CPU is the part of the computer that actually runs programs. It reads program instructions and data from memory, performs operations on data, and stores the results of operations into memory. It also controls the peripherals, sending instructions and reading back data or status information.

The memory is used for storing program instructions, data, and temporary results used by the CPU. Computer memory is divided up into units small enough for the CPU to manipulate. Each memory unit has a unique **address**, which can be thought of as a number describing the position of that unit relative to the beginning of the memory. The CPU reads or writes a particular memory unit by specifying its address using the **address lines** of the bus. Data are passed to or from the memory using the **data lines** of the bus. Other information, such as read and write commands and timing, are passed to the memory using the **control lines** of the bus.

Peripherals are the computer's communication with the "outside world"—computer users, other computers, or instruments. Examples of peripherals are CRT displays, printers, keyboards, cassette recorders, disk drives, modems, thermocouples, and relay closures. The Carrier and Instrument Modules of your PCI-20000 System are peripherals, and you need to know something about how a computer treats peripherals in order to use your PCI-20000 System effectively.

The CPU communicates with peripherals in much the same way as it communicates with memory. Each peripheral has one or more **registers**, which are similar to memory units. Registers have addresses which permit the CPU to select a particular register to read or write in much the same way as it selects memory. Each peripheral may have several registers and therefore several register addresses. The CPU **writes** a peripheral register when it sends data to be displayed (e.g., to a CRT or printer) or

controls the peripheral (e.g., to open relay closures). The CPU **reads** a peripheral register to get incoming data (e.g., from a keyboard) or to determine the status of the peripheral (e.g, to see if a printer is ready). These operations are ordinarily described as **input** (reading a peripheral register) and **output** (writing a peripheral register). Input and output are complementary functions and are usually discussed together as "I/O".

A.2 Computer Numbers

All computers use "binary numbers" for their internal operations. The building blocks of binary numbers are cells, each of which has two states (voltage levels) and can therefore represent either a one or a zero. In order to represent larger numbers, many such cells are required. Each cell is assigned a value which is a power of two, and the cell's contribution to the number being represented is its value multiplied by one or zero, depending on the state of the cell. These cells are analogous to the digits used to represent ordinary decimal numbers, and are called **bits**, or **bi**nary dig**its**.

Here is an example of a binary number:

1 0 1 1 0

The bits denote powers of two, starting with 2^0 at the right, or **least-significant**, bit, through $2^4=16$ at the left, or **most-significant**, bit. The value of this number in ordinary decimal notation can be calculated as follows, starting with the least-significant bit:

$(0 * 2^0) + (1 * 2^1) + (1 * 2^2) + (0 * 2^3) + (1 * 2^4)$

$= (0 * 1) + (1 * 2) + (1 * 4) + (0 * 8) + (1 * 16) = 22$

Bits can be grouped to represent larger numbers in several ways. The smallest commonly used size for such groups is eight bits, called a **byte**. With eight bits, any number from 0 to 255 can be represented. A pair of bytes together form a 16-bit entity called a **word** and can represent any number from 0 to 65,535. Eight-bit bytes have become standards for processors used in inexpensive microcomputers. These "8-bit" processors can manipulate eight bits of data at a time and can usually select any of 65,536 different bytes with a 16-bit counter.

A bit sequence can also be given other interpretations. A byte can represent any one of 256 different values or quantities, which may or may not correspond to numbers. One common choice is to represent numbers from -128 to 127 rather than from 0 to 255.

Bytes are frequently used to stand for text characters. All upper- and lower-case letters, numbers, punctuation, and many special symbols can be easily represented in this fashion. Several codes have been devised to represent text characters as numbers, the most commonly used of which is the American Standard Code for

Information Interchange (ASCII). This code represents 128 different characters and special symbols using seven bits, with the eighth bit used as a **parity**, or error-detection code. Bytes can be grouped together to represent larger numbers or more complicated quantities. For example, a word (two bytes) can represent a number from 0 to 65,535 or from -32,768 to 32,767. A sequence of several bytes might be used to represent a complex instruction to the CPU.

A.3 Data Signals

The purpose of your PCI-20000 System is to translate real-world data into a form which your computer (and you) can understand. Real-world data signals may take a wide variety of forms: voltage, current, resistance, temperature, light intensity, weight, and so on. In general, the signals fall into one of two categories, **digital signals** and **analog signals.**

Digital signals, which would be more accurately described as binary signals, are signals which exist in one of two states, variously referred to as: on or off; high or low; true or false. Digital input signals might be generated by switches or alarms. Digital output signals might be used to turn equipment on and off or to generate pulses to control a stepping motor.

Data are represented internally as voltage levels in the computer, so all signals must ultimately be represented as voltage levels appropriate to the computer circuitry. Most microcomputers today use TTL (transistor-transistor logic) and a 5-volt power supply. Signal levels must be at least +2.0 volts in order to be interpreted as "high", and voltages much outside the 0 to +5 volt range will damage the circuitry. **Buffered** TTL output circuits can sink on the order of 24 ma or source on the order of 14 ma in providing the desired output levels; higher requirements will result in incorrect output levels or damage to the circuitry.

In order to permit the computer to accept input signals and produce output signals outside the range of buffered TTL levels, or in forms such as current or frequency, the PCI-20000 System may be used. This System may include signal converters, voltage level converters, and isolation circuitry in the case of noisy signals or very high or low voltages. A digital signal, thus converted, is connected to the appropriate input line of a digital interface IC in the computer, which allows it to be read as a particular bit in a particular input register. Since the registers are generally 8-bit registers, several signals may be read at once. Similarly, digital output signals, originating at an output line of a digital interface IC, may be isolated and converted in level or signal type before reaching the equipment to be controlled.

Even if input and output signals are apparently in the right range to be connected directly to the input and output lines of the PCI-20000 System, some isolation is usually desirable. This helps to protect the System circuitry from transient voltages induced by the equipment being controlled or by external apparatus. Termination

panels, with provision for signal-conditioning or optical isolation, are available as a part of the PCI-20000 System.

Analog signals are signals which can vary continuously over some range. Typical analog input signals include temperature, speed, and pressure. Analog output signals are used to control meters, oscilloscopes, and chart recorders. Since our computers can directly handle only digital data, analog signals must be converted to digital signals for input to a computer. This is accomplished by a special device called an Analog-to-Digital Converter (A/D or ADC). Similarly, analog output signals are produced by converting digital output from the computer with a Digital-to-Analog Converter (D/A or DAC).

Since an analog signal can have any value whatsoever within its range, it can never be measured with absolute precision. The **resolution** of an analog measurement is determined by the number of bits of the digital signal to which it is converted, and the range of conversion. The most common A/D converters now have 12- bit resolution, or roughly 3-1/2 digits. Consider, for example, a 12-bit measurement with an input range of -10 to +10 volts. The digital signal produced by the converter can have $2^{12} = 4096$ possible values. Each step corresponds to 20/4096 = 0.00488 volts. You should be aware that the **accuracy** of the measurement is affected by other factors in addition to the resolution of the converter. These factors include the linearity of the converter, any signal conditioning or amplification stages used, and the amount of noise introduced by the entire measurement system.

The most expensive components of an analog input system are usually the amplifier and A/D converter. In order to sample several analog inputs with this circuitry, a **multiplexer**, or **mux**, is used to connect the input signals one at a time to the converter. Such an arrangement is called a Data Acquisition System (DAS). The number of input channels available is determined by the capacity of the mux. The rate at which input channels can be sampled is determined by the conversion speed of the the A/D and the time required for the mux to switch channels. The efficiency of the system may be improved by adding a sample-and-hold circuit so that switching may be done without waiting for the conversion to be completed.

A D/A converter provides the capability of producing analog output signals based on the internal digital data of the computer. The voltage or current output is determined by the digital value sent to the converter and by the output signal range. The smoothness and accuracy of the output signal is determined by the resolution of the D/A and by the rate at which the signal can be changed (slew rate of the converter). The output signal can be further smoothed by filtering.